Optimizing Quantitative Structure Model (QSMs) parameters for Coastal Redwoods (*Sequoia sempervirens*) for accurate aboveground biomass estimates

Alexander Barajas-Ritchie

Dr. Lisa Patrick Bentley

Paris Krause

Brieanne Forbes

Abstract
In northern California, there is an abundance of *Sequoia sempervirens* trees (coastal redwoods). These redwood trees provide many essential environmental services, one of which is sequestering carbon via their considerable amount of aboveground biomass (AGB). Determining the amount of carbon that these trees store in their AGB is a crucial part of carbon accounting, a quantification of greenhouse gas emissions. However, measuring AGB is difficult to calculate as destructive harvesting of trees is needed. Alternatively, allometric equations developed from destructive sampling can be used to estimate AGB via tree diameter and/or height measurements. Unfortunately, these measurements are time consuming, and their accuracy is contingent on applying them to trees with similar ages and growth environments as those used for the allometric equation development. Here, we capitalize on remote sensing technology, specifically, a terrestrial laser scanner (TLS) to non-destructively estimate AGB of coastal redwood trees. My goal was to first optimize parameters of quantitative structure models (QSM) to estimate tree volume and then compare AGB estimates from the TLS-QSM approach to AGB estimates from diameter and height measurements measured in the field and applied to published allometric equations. We found that our optimized parameters in creating QSMs yielded similar AGB results to published allometric equations. The results from this study are important because they will allow us to better estimate coastal redwood AGB in specific areas of Sonoma County, which will allow for improved carbon accounting and appropriate planning of forest and timber management.

Introduction
In northern California, there is an abundance of coastal redwoods (*Sequoia sempervirens*) that provide essential ecosystem services and are valuable timber species. Redwoods possess a considerable amount of aboveground biomass (AGB) which is critical for carbon accounting to quantify greenhouse gas emissions and carbon sequestration of forests. Typically, destructive harvesting of trees is used to estimate AGB, but this is time consuming and difficult. Accurately calculating AGB without destructive sampling is challenging due to the variability in size, complexity, and regional environmental factors of each tree which might not match the trees and locations where the equations were developed (Anderson-Teixeira et al. 2015). Ideally, when destructive sampling is not possible, AGB allometric equations can be used, but should be calculated from a large sample size of trees within specific regions and accuracy depends on destructive or partial-destructive sampling to create and improve allometries. For example, Sillett et al. (2018) found AGB estimates to be most accurate when using different allometries depending on stand age.

In northern California, Kizha and Han (2016) and Sillett et al. (2018) created allometric equations from redwoods in Humboldt County and Mendocino County, respectively, but no such known studies have occurred in Sonoma County. Alternative methods to destructive sampling, such as using Light detecting and ranging (LiDAR) and quantitative structure models (QSMs), could prove to be more accurate and sustainable. In this project, we developed, optimized, and processed QSMs created from terrestrial laser scanning (TLS) data to calculate the AGB of redwood trees. We then compared QSM estimates to national level equations from FIA, Jenkins et al. 2003 and Chojnacky et al. 2013, along with California local Sillett et al. (2018) AGB estimates.

Methods

Figure 1

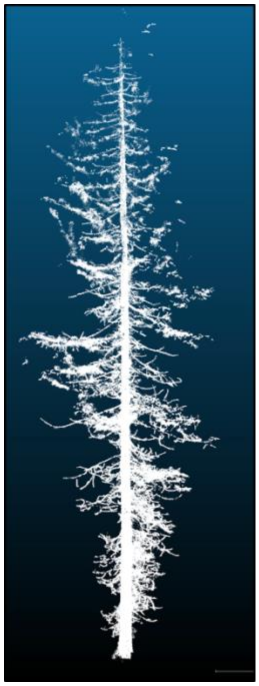

Figure 2

Circular plots (11.3m radius) at Saddle Mountain Ag+ Open Space Preserve in Sonoma County were scanned with a Riegl VZ-400i TLS in Summer 2020. The TLS uses LiDAR technology to create a 3D point cloud representation of the plot by sending out a pulse and returning back with an x, y, z coordinate. We scanned 18 times in the plot and then co-registered and georeferenced all scans at the plot level using Riscan Pro software. We then used Lidar360 software to normalize each plot .las file by digital elevation model and extract each individual redwood tree from the plot. Once extracted, the 3D point cloud of each tree was manually cleaned using Cloud Compare to remove any points that did not appear to belong to the specified tree. Each tree was saved as an x, y, z matrix text file (Figure 1). Individually, each tree point cloud text file was then processed through a Python TLSeparator library to remove all of the leaves and leave only the wood structure. The genetric_tree() function was used to produce the wood structure pointcloud (Figure 2). The nopath_genetric_tree() function was also used in addition if the generic_tree() function errored. Possible causes for erroring were point cloud noise and/or atypical tree structure.

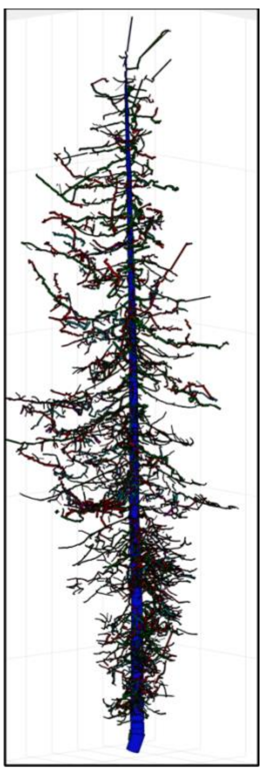

Figure 3

The wood structure point cloud trees were then processed through TreeQSM 2.4, a MATLAB library used to fit a hierarchically structured 3D cylinder model on a tree point cloud. (Figure 3) Each tree point cloud was downsampled and normalized to speed up the QSM process. This was accomplished using TreeQSM's cubical_down_sampling() function. To produce the best model, ten models were created using a predetermined input parameter file. Once created, we selected the optimum model based on 'cyl_vol_dia10_mean'. Twenty- five more models were then created based on the optimum inputs from the first run.

Results

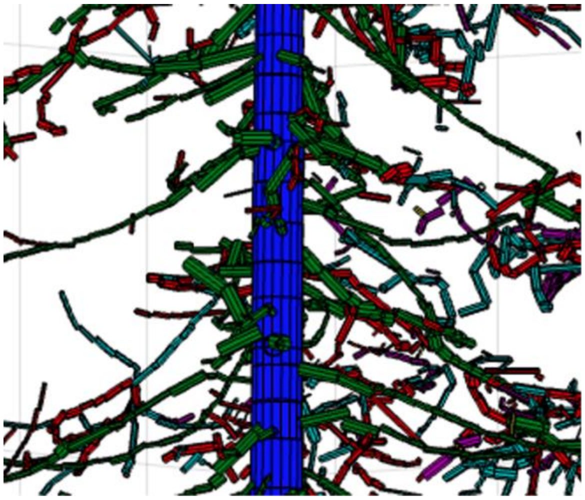

Figure 4

In general, for all the optimized redwood QSMs, the trunk cylinders (blue) were well-formed, straight, and without gaps. The branch cylinders (green, red, turquoise) resembled the branch structural pattern from the original wood structure point cloud (Figure 2) inferring an accurate QSM. By visually inspecting the cylinders and a cross section (Figure 4), we closely examined each tree for errors. These errors were typically presented as dense cylinder clusters. We were able to avoid these issues and yield the best and most consistent results by sorting the redwood point clouds into small, medium, and large parameter sets based on height classes (Table 1).

Table 1	Small	Medium	Large
Height range	2 m - 9.9 m	10m - 24.9m	25m - 40 m
Parameters	PatchDiam1 = [0.020 .03] PatchDiam2Min = [0.0030 .0060 .0090 .012] PatchDiam2Max = [0.0150 .020 .025] BallRad1 = PatchDiam1+0.007 BallRad2 = PatchDiam2Max+0.003	PatchDiam1 = [0.045 .08] PatchDiam2Min = [0.0080 .0130 .0180 .023] PatchDiam2Max = [0.010 .0150 .02] BallRad1 = PatchDiam1+0.02 BallRad2 = PatchDiam2Max+0.01	PatchDiam1 = [0.090 .11] PatchDiam2Min = [0.0110 0.0160 0.0210 0.026] PatchDiam2Max = [0.013 .0180 .05] BallRad1 = PatchDiam1+0.04 BallRad2 = PatchDiam2Max+0.02

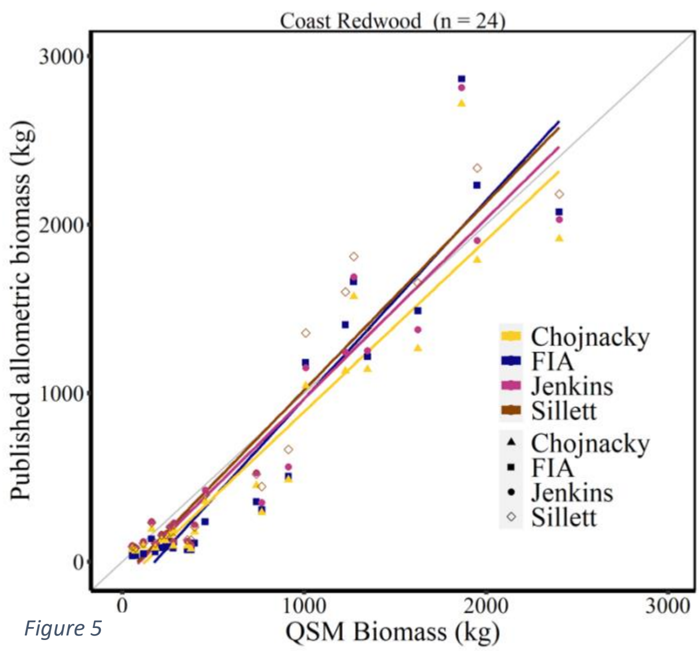

Figure 5

When we compared our TLS-QSM estimates of AGB to published allometric models for calculating redwood biomass (Chojnacky, FIA, Sillett, etc.) we found that all approaches produced similar results.

Discussion

In our study we aimed to calculate AGB of coast redwoods in Sonoma County using a non-destructive approach via TLS and QSMs. Ultimately, we were able to calculate AGB of redwoods using our approach but found that this approach was very sensitive to specific post-processing steps.

First, we found that the leaf separator python script was a critical component to this process as leaves and noise from the TLS scan prevent cylinders from properly fitting and produce an inaccurate volume. Thus, a good wood structure point cloud was critical for producing a usable QSM. Poor quality TLS point cloud scans or wind during scanning made the leaf separator less effective and the quality of the original point cloud had a profound effect on the processing pipeline.

Second, we observed that the QSM process heavily relied on five input parameters which adjust how the algorithm attempts to fit the cylinders and greatly influenced our results. We originally started with the suggested parameter sets on page 24 of the TreeQSM 2.4 documentation, but these did not work well with our trees. Indeed, different parameter sets directly and drastically affected the QSMs ability to fit cylinders on the point cloud. We settled on three sets of input parameters centered around heights which provided QSM success. Importantly, trees on the borders of the height classifications had some issues with fitting QSMs. In the future, we could re-factor the parameter sets from three height ranges to six for a potential higher detail and improved cylinder fitting.

Conclusion

Due to the need for accurate forest carbon accounting for forest management, controlled burns, and understanding forest ecosystem health, this study is significant as it shows that we can use optimized QSMs generated from TLS data to determine the AGB of coast redwoods without destructive sampling. Importantly, the QSM fitting procedure is sensitive to certain steps, such as leaf separation, input parameters based on height class and the quality of the TLS scans, but by controlling for these issues, we can estimate the AGB of coastal redwoods in Sonoma County with great confidence.

Acknowledgments

Dr. Phil Wilkes
Dr. Alvaro Lau
Dr. Pasi Raumonen
Alanna Post
Save the Redwoods Foundation

References

Anderson-Teixeira, K. J., McGarvey, J. C., Muller-Landau, H. C., Park, J. Y., Gonzalez-Akre, E. B., Herrmann, V., Bennett, A. C., So, C. V., Bourg, N. A., Thompson, J. R., McMahon, S. M., & McShea, W. J. (2015). Size-related scaling of tree form and function in a mixed-age forest. Functional Ecology, 29(12), 1587–1602. https://doi.org/10.1111/1365-2435.12470

California Air Resources Board (CARB). 2014. Compliance Offset Protocol U.S. Forest Offset Protocol.

Chojnacky, D. C., Heath, L. S., & Jenkins, J. C. (2013). Updated generalized biomass equations for North American tree species. Forestry, 87(1), 129–151. https://doi.org/10.1093/forestry/cpt053

Canadell, J. G., & Schulze, E. D. (2014). Global potential of biospheric carbon management for climate mitigation. Nature Communications, 5(1), 5282. https://doi.org/10.1038/ncomms6282

Disney, M., Burt, A., Wilkes, P. et al. New 3D measurements of large redwood trees for biomass and structure. Sci Rep 10, 16721 (2020). https://doi.org/10.1038/s41598-020-73733-6

Duncanson, L. et al. Implications of allometric model selection for county-level biomass mapping. Carbon Balance Manag. 12(1), 18 (2017).

Jenkins, J. C., Chojnacky, D. C., Heath, L. S., Birdsey, R. A. (2003). National scale biomass estimators for United States tree species. Forest Science. (49), 12-35.

Sillett, S. C. et al. Allometric equations for Sequoia sempervirens in forests of different ages. For. Ecol. Manag. 433, 349–363 (2019).
]